COLOR TWISTED NEMATIC LIQUID CRYSTAL DISPLAYS

FIELD OF THE INVENTION

This invention relates to novel designs for color twisted nematic liquid crystal displays.

BACKGROUND OF THE INVENTION

Color liquid crystal displays (LCDs) are usually made by putting color filters onto the individual pixels of a liquid crystal display. These color filters are resins with color pigments. Full color displays can be made by a combination of the red, green and blue primary colors. This coloring scheme is the predominant technology for active matrix as well as passive matrix LCDs currently in use. Many colors can be obtained.

For many applications, multiple colors rather than a full range of colors may be sufficient. This is especially true for low cost products not requiring full video displays. There have been several proposals to produce a color effect without the use of color filters. The advantages of colors without color filters are many, the most important one being cost and ease of manufacturing. Yamaguchi et al, Yamaguchi et al and Yang et al teach the generation of color by the addition of a birefringent film inside the LCD. The birefringence color is due to the interference effect and dispersion effect of the transmission of the LC cell. While most of the attention is concentrated on the supertwisted nematic (STN) display with a twist angle of larger than 180°, there is

nevertheless a need for similar techniques for low twist angles. Such displays have not been studied systematically.

SUMMARY OF THE INVENTION

The present invention provides a proper set of values for the twist angle, the cell birefringence and the input/output polarizer angles, from which it is possible to obtain vivid colors in low twist LCDs without the use of color filters. Such displays have many applications in situations requiring only a few colors without gray scales.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments of the invention will now be described by way of example and with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a transmittive LCD cell,

Figure 2 is a schematic diagram of a transflective LCD cell,

Figure 3 is a schematic diagram of a reflective LCD cell,

Figure 4 is a schematic diagram of the various directions and vectors of a LCD cell,

Figure 5 is the transmission spectrum of the zero volt state of the first preferred embodiment,

Figure 6 is the color coordinate of the liquid crystal display output of the first preferred embodiment as the voltage is changed,

Figure 7 is the transmission spectrum of the zero volt state of the second preferred embodiment,

Figure 8 is the color coordinate of the liquid crystal display output of the second preferred embodiment as the voltage is changed,

Figure 9 is the transmission spectrum of the zero volt state of the third preferred embodiment,

Figure 10 is the color coordinate of the liquid crystal display output of the third preferred embodiment as the voltage is changed,

Figure 11 is the transmission spectrum of the zero volt state of the fourth preferred embodiment,

Figure 12 is the color coordinate of the liquid crystal display output of the fourth preferred embodiment as the voltage is changed,

Figure 13 is the transmission spectrum of the zero volt state of the fifth preferred embodiment,

Figure 14 is the color coordinate of the liquid crystal display output of the fifth preferred embodiment as the voltage is changed,

Figure 15 is the transmission spectrum of the zero volt state of the sixth preferred embodiment,

Figure 16 is the color coordinate of the liquid crystal display output of the sixth preferred embodiment as the voltage is changed,

Figure 17 is the transmission spectrum of the zero volt state of the seventh preferred embodiment,

Figure 18 is the color coordinate of the liquid crystal display output of the seventh preferred embodiment as the voltage is changed,

Figure 19 is the transmission spectrum of the zero volt state of the eighth preferred embodiment

Figure 20 is the color coordinate of the liquid crystal display output of the eighth preferred embodiment as the voltage is changed,

Figure 21 is the transmission spectrum of the zero volt state of the ninth preferred embodiment, and

Figure 22 is the color coordinate of the liquid crystal display output of the ninth preferred embodiment as the voltage is changed.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A liquid crystal display is composed of a liquid crystal layer **3** and a front polarizer **1**. The liquid crystal layer is held between two pieces of glass **2** and **4**. On these glasses, there can be conductive transparent electrodes, alignment layers and other coatings necessary for making the display. For a transmittive display, a rear polarizer **5** is added as shown in Figure 1. For the case of a transflective display, a diffusive reflector **6** can also be added as shown in Figure 2. In the case of a single polarizer reflective display, the rear polarizer **5** is eliminated as shown in Figure 3. A special reflector **7**, which does not produce any depolarization effect, will then have to be used.

The transmission or reflection properties of a LCD is completely characterized by its input polarizer angle α, the cell gap d - birefringence Δn product, $d\Delta n$, the twist angle of the liquid crystal ϕ, and the output polarizer angle γ. All these angles are measured relative to the input director of the LCD cell which is defined as the x-axis. The various directions inside a LC cell are shown in Figure 4. The twist angle ϕ is the angle between the input and output directors. The input and output polarizers are at angles relative to the input director.

By varying the set of values ($\alpha, \gamma, \phi, d\Delta n$) one can obtain any color for the display at the no voltage bias V=0 state. The transmission spectrum is simply given by the Jones matrix calculation

$$T = \left| \begin{pmatrix} \cos\gamma & \sin\gamma \end{pmatrix} \bullet M_{LC} \bullet \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix} \right|^2 \tag{1}$$

where $$M_{LC} = \begin{pmatrix} A - iB & -C - iD \\ C - iD & A + iB \end{pmatrix} \tag{2}$$

and

$$A = \cos\phi\cos\chi + \frac{\phi}{\chi}\sin\phi\sin\chi \tag{3}$$

$$B = \frac{\delta}{\chi}\cos\phi\sin\chi \tag{4}$$

$$C = \sin\phi\cos\chi - \frac{\phi}{\chi}\cos\phi\sin\chi \tag{5}$$

$$D = \frac{\delta}{\chi}\sin\phi\sin\chi \tag{6}$$

and

$$\chi = \left(\delta^2 + \phi^2\right)^{1/2} \tag{7}$$

$$\delta = \pi d\Delta n / \lambda \tag{8}$$

$$\Delta n = n_e(\theta) - n_o \tag{9}$$

where λ is the wavelength. By varying the parameters ($\alpha, \gamma, \phi, d\Delta n$), combinations can be found that will produce color LCDs without requiring any color filters. The search can then be further refined by applying a voltage to the LCD and finding its color change. This requires the calculation of the deformation of the liquid crystal director arrangement by solving the Euler-Lagrange equations. In the optimization procedure, the deformation of the liquid crystal alignment may be calculated as a function of applied voltage. Then the transmission spectra as a function of the applied voltage are calculated. The results are evaluated in terms of its colors. Finally, several modes where the color changes are vividly obtained as a function of applied voltage are recorded.

For the case of the single polarizer reflective display, the reflectivity is given by

$$R = \left| \begin{pmatrix} \cos\alpha & \sin\alpha \end{pmatrix} \bullet R_{\phi} M_{LC}^{*} R_{\phi}^{-1} M_{LC} \bullet \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix} \right|^2$$

where the transformation matrix R is given by

$$R_{\phi} = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix}$$

The same procedure of varying ($\alpha, \phi, d\Delta n$) to find the best combination with the best colors can be performed as in the transmittive display. For the reflective display, the

search is simpler because of the reduction of one variable. All the new combinations of (α, ϕ, $d\Delta n$) are recorded here.

In its preferred embodiments the present invention provides values of (α, γ, ϕ, $d\Delta n$) for obtaining vivid color LCDs without using color filters. These results can be generalized into several categories.

In the first category, the background of the display is yellowish green or light colors. This is the color of the display without an applied voltage or before the applied voltage affects the liquid crystal alignment. The other colors such as purple, blue, red, orange are obtained by applying a higher voltage. Within this group, the value of can take on 2 values depending on the brightness contrast required. In general, for this group of displays, the following rules are obeyed:

- $\alpha \sim 45^{o}$
- $\gamma \sim 135^{o} - \phi$
- ϕ can be any value
- $d\Delta n \sim 1.3\mu m$ or $0.79\mu m$

In the second group of displays, the background of the display is light yellow. This is the color of the display without an applied voltage or before the applied voltage affects the liquid crystal alignment. The other colors such as purple, blue, red, orange are obtained

by applying a higher voltage. In general, for this group of displays, the following rules are obeyed:

- $\alpha \sim 45^{o}$
- $\gamma \sim 45^{o} - \phi$
- ϕ can be any value
- $d\Delta n \sim 1.1\mu m$

In the third category, the display is of a single polarizer reflective type. In this case, the general rules discovered are

- $\alpha \sim 45^{o}$
- ϕ can be any value smaller than 60^{o}
- $d\Delta n \sim 0.5\text{-}0.6\mu m$

In the first preferred embodiment of this invention, the LCD is of a transmittive type. The ($\alpha, \gamma, \phi, d\Delta n$) values are ($45^{o}$, 30^{o}, 75^{o}, $1.3\mu m$). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 5. This display is green when the applied voltage is zero. When a voltage bias is applied, the color will change to blue, purple, yellow, orange, pink and other colors depending on the voltage. Figure 6 shows the trajectory of the color coordinates in the CIE (Commission International de l'Eclairage) chart when the applied voltage is varied.

In the second preferred embodiment of this invention, the LCD is of a transmittive type. The (α, γ, ϕ, $d\Delta n$) values are (45°, 45°, 90°, 1.3μm). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 7. This display is green when the applied voltage is zero. When a voltage bias is applied, the color will change to blue, purple, yellow, orange, pink and other colors depending on the voltage. Figure 8 shows the trajectory of the color coordinates in the CIE chart when the applied voltage is varied.

In the third preferred embodiment of this invention, the LCD is of a transmittive type. The (α, γ, ϕ, $d\Delta n$) values are (45°, -45°, 90°, 1.1μm). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 9. This display is yellow when the applied voltage is zero. When a voltage bias is applied, the color will change to blue, purple, yellow, orange, pink and other colors depending on the voltage. Figure 10 shows the trajectory of the color coordinates in the CIE chart when the applied voltage is varied.

In the fourth preferred embodiment of this invention, the LCD is of a transmittive type. The (α, γ, ϕ, $d\Delta n$) values are (45°, 90°, 130°, 1.3μm). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 11. This display is yellowish green when the applied voltage is zero. When a voltage bias is applied, the color will change to blue, purple, yellow, orange, pink and other colors

depending on the voltage. Figure 12 shows the trajectory of the color coordinates in the CIE chart when the applied voltage is varied.

In the fifth preferred embodiment of this invention, the LCD is of a transmittive type. The (α, γ, ϕ, $d\Delta n$) values are (45°, 30°, 75°, 0.79μm). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 13. This display is green when the applied voltage is zero. When a voltage bias is applied, the color will change to blue, purple, yellow, orange, pink and other colors depending on the voltage. Figure 14 shows the trajectory of the color coordinates in the CIE chart when the applied voltage is varied. This is actually similar to the first preferred embodiment except for a lower value of $d\Delta n$.

In the sixth preferred embodiment of this invention, the LCD is of a transmittive type. The (α, γ, ϕ, $d\Delta n$) values are (45°, 45°, 90°, 0.79μm). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 15. This display is green when the applied voltage is zero. When a voltage bias is applied, the color will change to blue, purple, yellow, orange, pink and other colors depending on the voltage. Figure 16 shows the trajectory of the color coordinates in the CIE chart when the applied voltage is varied. This is actually similar to the second preferred embodiment except for a lower value of $d\Delta n$.

In the seventh preferred embodiment of this invention, the LCD is of a transmittive type. The (α, γ, ϕ, $d\Delta n$) values are (45°, 45°, 90°, 0.85μm). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 17. This display is yellow when the applied voltage is zero. When a voltage bias is applied, the color will change to blue, purple, yellow, orange, pink and other colors depending on the voltage. Figure 18 shows the trajectory of the color coordinates in the CIE chart when the applied voltage is varied. This is actually similar to the third preferred embodiment except for a lower value of $d\Delta n$.

In the eighth preferred embodiment of this invention, the LCD is of a transmittive type. The (α, γ, ϕ, $d\Delta n$) values are (45°, -45°, 5°, 0.9μm). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 19. This display is yellow when the applied voltage is zero. When a voltage bias is applied, the color will change to blue, purple, yellow, orange, pink and other colors depending on the voltage. Figure 20 shows the trajectory of the color coordinates in the CIE chart when the applied voltage is varied. This is actually similar to the third preferred embodiment except for a lower value of $d\Delta n$.

In the ninth preferred embodiment of this invention, the LCD is of a reflective type. The (α, ϕ, $d\Delta n$) values are (45°, 10°, 0.56μm). The transmission spectrum of this display can be calculated using equation (1). The result is shown in Figure 21. This display is yellow when the applied voltage is zero. When a voltage bias is applied, the color will change to

blue, purple, yellow, orange, pink and other colors depending on the voltage. Figure 22 shows the trajectory of the color coordinates in the CIE chart when the applied voltage is varied. This is actually similar to the third preferred embodiment except for a lower value of $d\Delta n$.